An Adaptive MAC Protocol for Ad-Hoc Wireless LANs

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***Abstract*— An ad-hoc Learning Automata-based protocol for wireless LANs, capable of operating efficiently under bursty traffic conditions, is introduced. According to the proposed protocol, the mobile station that is granted permission to transmit is selected by means of Learning Automata. The Learning Automaton takes into account the network feedback information in order to update the choice probability of each mobile station. The proposed protocol is compared via simulation to TDMA under bursty traffic conditions and is shown to exhibit superior performance even when the network feedback is noisy.**

I. Introduction

There are fundamental differences between wireless and wired LANs that pose difficulties in the design of Medium Access Control (MAC) protocols for wireless LANs (WLANs) [1]. The wireless medium is characterized by bit error rates (BER) having an order of magnitude even up to ten orders of magnitude of a LAN cable's BER. Furthermore, in WLANs errors occur in bursts, whereas in traditional wired systems errors appear randomly. Finally, a fully connected topology between the nodes of a WLAN cannot be assumed. As a result, WLANs are characterized by unreliable links between nodes resulting in bursts of errors and dynamically changing network topologies.

Modern WLAN MAC protocols should be able to efficiently handle the bursty traffic that is expected to be generated by WLAN applications (such as client/server and file transfer applications between WLAN nodes). This paper proposes AHLAP, an ad-hoc Learning Automata-based wireless MAC protocol for wireless LANs. Learning Automata are efficient structures that can provide adaptation to systems operating in changing and/or unknown environments [2], [3]. According to AHLAP, the mobile station that grants permission to transmit is selected by means of Learning Automata. The Learning Automata take into account the network feedback information in order to update the choice probability of each mobile station. The network feedback conveys information on the traffic pattern of the network. The learning algorithm asymptotically tends to assign to each station a portion of the bandwidth proportional to the station's needs.

II. The Ad-Hoc Learning-Automata-based Protocol (AHLAP)

According to AHLAP, each mobile station is equipped with a Learning Automaton [4],[5],[6] which contains the choice probability Π_i for each mobile station u_i in the network. The protocol operates as follows: After the network feedback is received for the transmission at slot t, at each station u_i the basic choice probabilities are normalized in the following way:

$$\Pi_i(t) = \frac{P_i(t)}{\sum_{k=1}^{N} P_k(t)} \tag{1}$$

Clearly, $\sum_{i=1}^{N} \Pi_i(t) = 1$, where N is the number of mobile stations. In the beginning of slot t, the normalized probabilities $\Pi_i(t)$ are used to grant permission to transmit to a mobile station.

At each time slot t, the basic choice probability $P_i(t)$ of the selected station u_i is updated according to the network feedback information. If station u_i transmitted a packet during slot t, then its basic choice probability is increased. Otherwise, if station u_i was idle, its basic choice probability is decreased. The following probability updating scheme is used:

$$\begin{aligned}
&P_i(t+1) = P_i(t) + L(1 - P_i(t)),\\
&\text{if } u(t) = u_i \text{ and } SLOT(t) = SUCCESS\\[2ex]
&P_i(t+1) = P_i(t) - L(P_i(t) - a),\\
&\text{if } u(t) = u_i \text{ and } SLOT(t) = IDLE
\end{aligned} \tag{2}$$

For all t, it holds that $L, a \in (0,1)$ and $P_i(t) \in (a,1)$. L governs the speed of the automaton convergence. The selection procedure for a value of L reflects the classic speed versus accuracy problem. The lower the value of L the more accurate the estimation made by the automaton, a fact however that comes at expense over convergence speed. The role of parameter a is to enhance the adaptivity of the protocol. This is because when the choice probability of a station approaches zero, then this station is not selected for a long period of time. During this period, it is probable that the station transits from idle to busy state. However, since the mobile station does not grant permission to transmit, the automaton is not capable of "sensing" such transitions. Thus, the use of a non-zero value for parameter a prevents the choice probabilities of the stations from taking values in the neighborhood of zero and increases the adaptivity of the protocol.

Since the offered traffic is of bursty nature, when the selected mobile station had a packet to transmit, it is probable that the selected station will also have packets to transmit in the near future. Thus, its choice probability is increased. On the other hand, if the selected station notifies that it does not have buffered packets, its choice probability is reduced, since it is likely to remain in this state in the near future.

AHLAP updates the choice probabilities of mobile stations according to the network feedback information. It is proved [7] that the choice probability of each mobile station converges to the probability that this station is not idle.

Based on the above discussion, it is clear that in a noiseless environment, AHLAP is collision-free. This is due to the fact that all stations use the same protocol and due to the broadcast nature of the wireless medium the network feedback is common for all stations. Therefore, at each slot, all stations choose the same station to be granted permission to transmit and the protocol is collision-free despite its distributed nature.

However, in a noisy environment, it is possible that the network feedback is not common for all stations. Thus, the choice probabilities values may be different at several network nodes and as a result collisions may occur since it is likely that two or more stations may sometimes not grant permission to transmit to the same station. In this case, the channel can be in one of the following three states: successful transmission, collision or idle. The simulation results presented in the next section take into account the following possibilities: a) A ”successful” slot is perceived by a station as ”idle”, due to the fact that this station is out of range of the transmitting one, b) a ”successful” slot is perceived by a station as a ”collision” one, due to bit errors imposed by the wireless channel, c) a ”collision” slot is perceived by a station as ”successful”, due to the power capturing phenomenon and d) a ”collision” slot it perceived by a station as ”idle”, due to the fact that this station is out of range of the transmitting ones.

In order to avoid excessive collisions, the probability distribution vectors which the automata use to operate must not greatly differ. However, such differences are likely to appear due to the erroneous nature of the network feedback. To this end, for each transmission performed by a station, the proposed protocol piggybacks the K largest probabilities in the station's data packet and the rest of the probabilities, which obviously correspond to those stations that are not favoured to transmit at this time, take the value of a. It is obvious that even with this mechanism, collisions will occur again. due to the noisy network feedback. However this time the dissemination of the probability distribution vector between the network stations helps stations have more common values for the probabilities and the received network feedback will be more accurate thus resulting to less collisions.

It is obvious that the selection for the value of K depends on the number of stations. If the network comprises a large number of stations N, then a selection for K with $K < N$ will limit the overhead caused by the protocol. The simulation results presented in the next section reveal that this mechanism leads to a satisfactory performance for AHLAP.

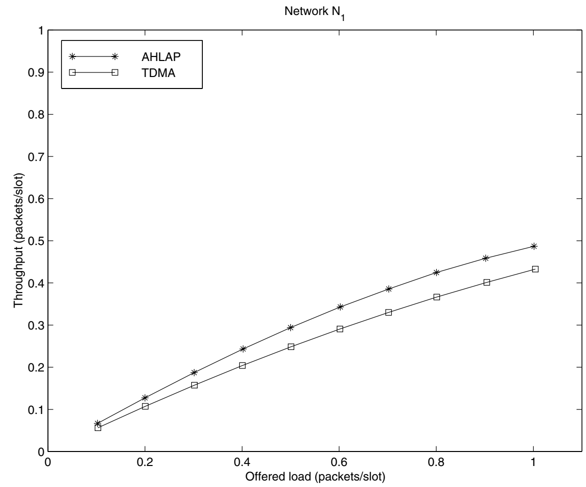

Fig. 1. The Throughput versus Offered load characteristics of AHLAP and TDMA when applied to network N_1.

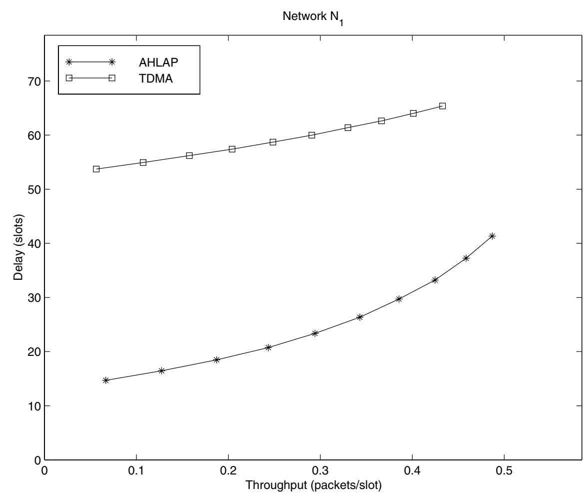

Fig. 2. The Delay versus Throughput characteristics of AHLAP and TDMA when applied to network N_1.

III. Performance Evaluation

Using simulation, we compared AHLAP against TDMA. The bursty traffic was modeled in the following way: We define ”time slot” as the time duration required for a data packet to be transmitted over the wireless link. Each source node can be in one of two states, S_0 and S_1. When a source node is in state S_0 then it has no packet arrivals. When a source node is in state S_1 then, at each time slot, it has a packet arrival with probability Z. Given a station is in state S_0 at time slot t, the probability that this station will transit to state S_1 at the next time slot is P_{01}. The transition probability from state S_1 to state S_0 is P_{10}. It can be shown that, when the load offered to the network is R packets/slot and the mean burst length is B slots, then the transition probabilities are: $P_{01} = \frac{R}{B(NZ-R)}$ and $P_{10} = \frac{1}{B}$. Each station uses a buffer to store the arriving packets. The buffer length is assumed to be equal to Q packets.

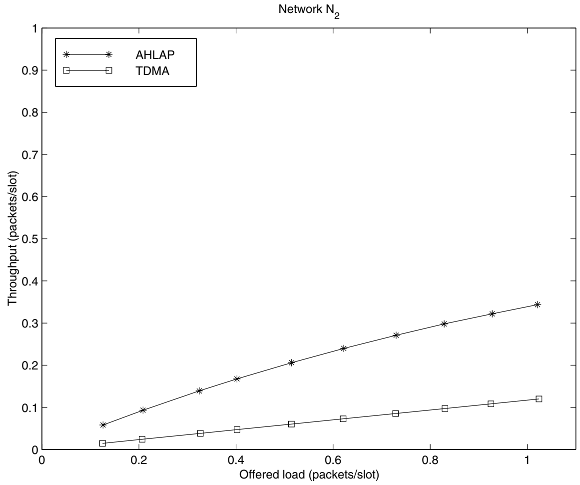

Fig. 3. The Throughput versus Offered load characteristics of AHLAP and TDMA when applied to network N_2.

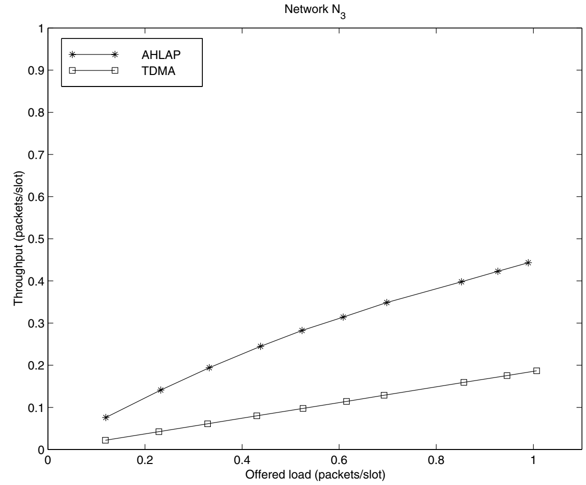

Fig. 5. The Throughput versus Offered load characteristics of AHLAP and TDMA when applied to network N_3.

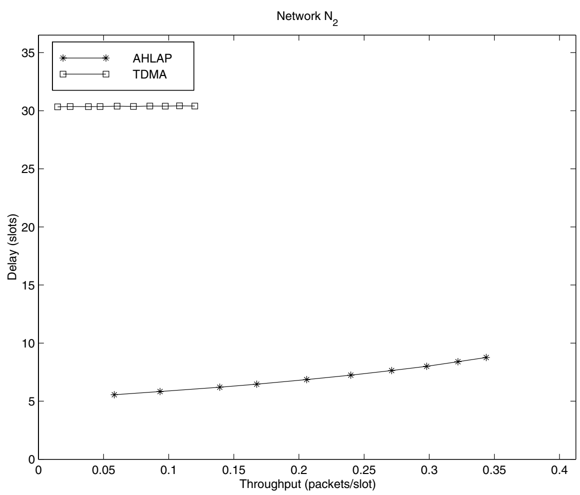

Fig. 4. The Delay versus Throughput characteristics of AHLAP and TDMA when applied to network N_2.

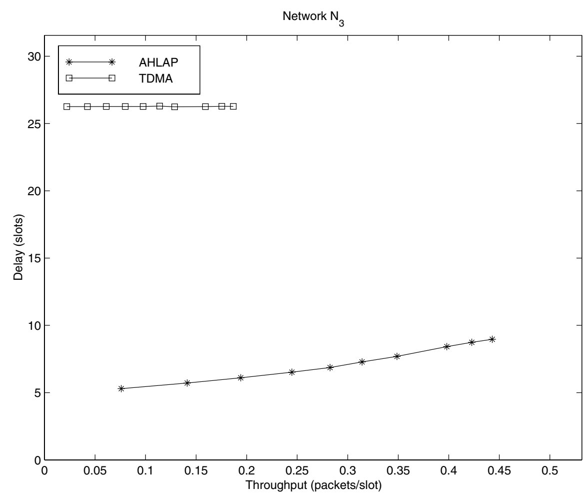

Fig. 6. The Delay versus Throughput characteristics of AHLAP and TDMA when applied to network N_3.

Any packets arriving to find the buffer full, are dropped.

In our simulation model, the condition of the wireless link between any two stations was modeled using a finite state machine with two states. Stage G, denotes that the wireless link is in a relatively "clean" condition and is characterized by a small BER, which is given by the parameter G_BER. Stage B, denotes that the wireless link is in a condition characterized by a high BER, which is given by the parameter B_BER. We assume that the background noise is the same for all stations and thus the principle of reciprocity stands for the condition of any wireless link. Therefore, for any two stations A and B, the BER of the link from A to B and the BER of the link from B to A are the same. The time periods spent by a link in states G and B are exponentially distributed, but with different average values, given by the parameters TG and TB. The status of a link probabilistically changes between the two states. When a link has spent its time in state G, the link transits either to stage B. When a link has spent its time in state B, the link transits to stage G.

We employed the broadly used a) throughput versus offered load and b) delay versus throughput performance metrics in order to compare the three protocols. We simulated the protocols for the following three different network configurations:

1) Network N_1: N=10, Q=10, B=10, Z=1.0.
2) Network N_2: N=10, Q=3, B=200, Z=0.7.
3) Network N_3: N=5, Q=5, B=1000, Z=0.8.

In these simulations, the following parameter values remain constant: G_BER=10^{-10}, B_BER=10^{-4}, TG= 30 sec, TB=10 sec, $k = 5$, R_LIM=1 and $P_c = 0.1$, $P_i = 0.1$. R_LIM sets the maximum number of retransmission attempts per packet. P_c is the probability that when two or more data packets collide, one of them is successfully decoded at the destination station due to the power capture phenomenon. P_i is the probability that a transmission does not get through to a certain station, thus this stations perceives the slot as idle. Finally, the DATA packet size is set to 1000 bits. The wireless medium bit rate was set to 1 Mbps and the propagation delay between any two stations was set to 0.0005 msec corresponding to inter-station distances of 150 meters.

Simulation results for the above-mentioned network configurations are shown in Figures 1-6. These results reveal the performance superiority of AHLAP over TDMA. It can be seen that the superiority of the proposed protocol is maintained albeit the noisy wireless environment, which causes the received feedback to be sometimes inaccurate. Furthermore, the burstier the traffic, the more increased the performance gain of AHLAP over TDMA.

IV. Conclusion

Modern WLAN MAC protocols should be able to efficiently handle the bursty traffic that is expected to be generated by WLAN applications. This paper proposes AHLAP, an ad-hoc Learning-Automata-based wireless MAC protocol. The protocol is able to achieve significantly higher throughput and lower delay values compared to TDMA under bursty traffic conditions in wireless environments. The main characteristics of AHLAP are:

1) It achieves a high performance, even when the offered traffic is bursty and the network feedback is noisy.
2) It is self-adaptive. Each station is assigned a fraction of the bandwidth proportional to its needs.
3) It is fully distributed, thus no centralized control of the network is required.
4) Due to its distributed nature, it is fault-tolerant, since its operation is not affected from a station failure.
5) It is very simple to implement. The only extra requirement over TDMA is the existence at of a processor at each station, which implements the learning algorithm.

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